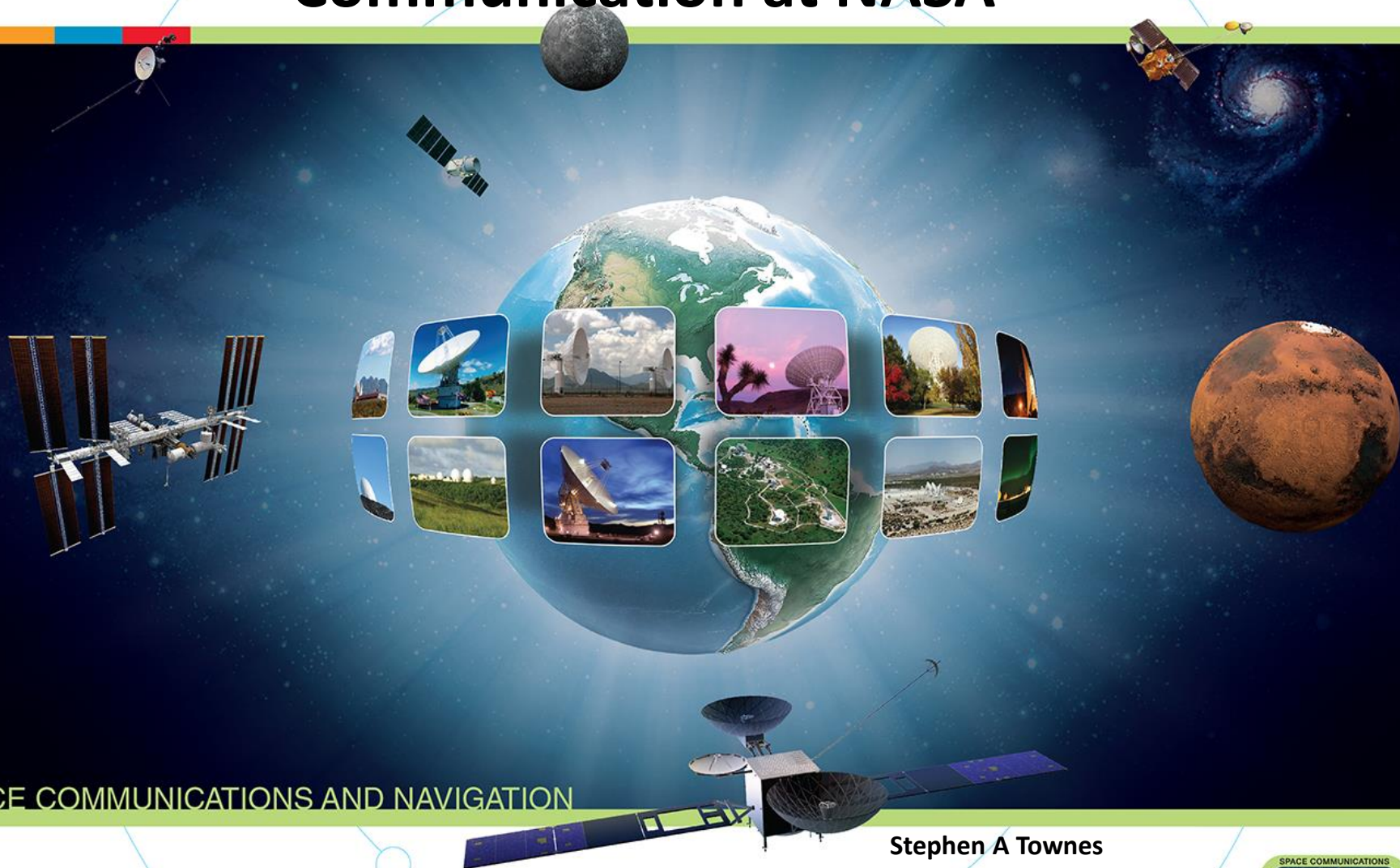


Status Update: Deep Space Optical Communication at NASA

National Aeronautics and
Space Administration



SPACE COMMUNICATIONS AND NAVIGATION

Stephen A Townes
Chief Technologist
Interplanetary Network Directorate
Jet Propulsion Laboratory
California Institute of Technology



Agenda

1. Deep Space Optical Communication (DSOC) Project
2. Proposed Hybrid RF-Optical Ground Station

National Aeronautics and
Space Administration



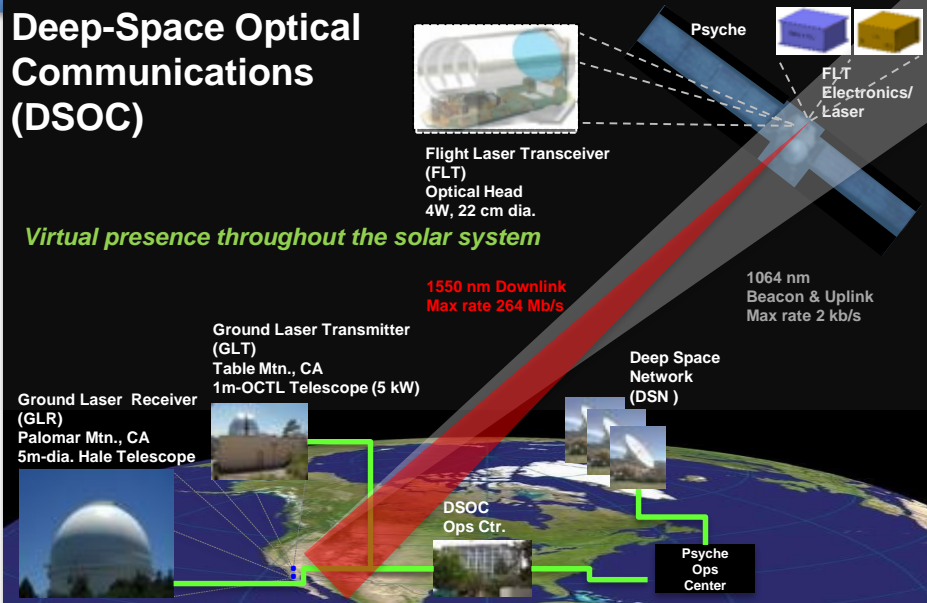
Jet Propulsion Laboratory
California Institute of Technology

Deep Space Optical Communications (DSOC) Project



Deep Space Optical Communications

Deep-Space Optical Communications (DSOC)



Objectives:

- **Demonstrate deep space optical communication capability**
 - Designed for 0.1 to 2.7 AU
 - Sun-Earth Probe Angle > 25° (TBC)
- **Develop a Flight Laser Transceiver (FLT) for accommodation on Psyche spacecraft**
 - Downlink data-rate of **0.256 - 200 Mb/s**
 - Uplink data-rate of **[2 kb/s]**
 - Prime demonstration duration **2 years**
- **Develop ground network**
 - GLT for transmitting laser beacon out to 2.7 AU
 - GLR retrofitted with photon counting receiver
 - Mission Operations System

Project Manager (PM) : Bill Klipstein
Project Technologist (PT): Abi Biswas

Sponsors:

STMD/TDM (flight), HEOMD/SCaN (ground), SMD (host)

Facilities:

Optical Comm and Environmental Test Labs at JPL
 Vendor site Labs and test facilities
 Optical Communication Telescope Laboratory (OCTL)
 Caltech Optical Observatories/Hale Telescope Observatory
 Psyche mission host

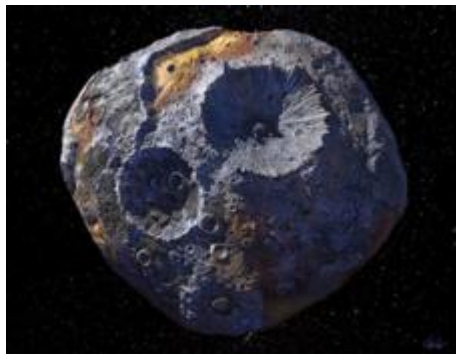
Key Milestones:

FY14-16 GCD Technology Development Phase
FY17 Phase A Start, SRR/MDR
FY18 PDR
FY19 CDR
FY20 Downlink I+T start at JPL
FY21 start I+T at Hale and OCTL
FY22 ORR
FY23-25 Launch, Ops

Note: New launch date may be in 2022

DSOC on Psyche

- Explores a metal world: a nickel-iron protoplanet core, a Trojan asteroid at ~ 3.3 AU
- PI: Lindy Elkins-Tanton, ASU
- PM: Henry Stone, JPL
- S/C: Space-Systems Loral
- Excellent opportunity for a robust demonstration of optical comm out to ~ 3 AU in 1st 2 years
- Psyche's schedule:
 - Launch in Oct 2023 corresponds to delivery of DSOC to S/C in June, 2022



- DSOC to operate during cruise
- Earth flyby at 1 year followed by Mars flyby at 1.75 years is near ideal for a 2 year DSOC demo
 - System shake out and demonstration of high data rates at closer ranges
 - Reaches farthest design distance inside 2 year mission lifetime

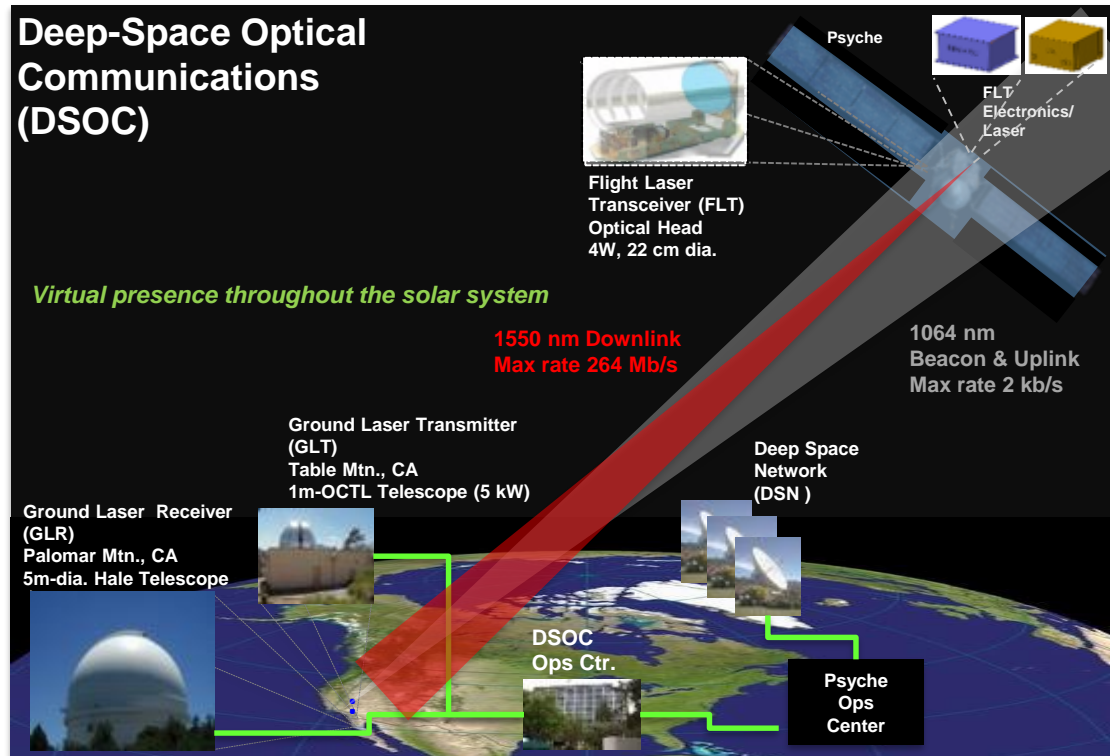
<https://sese.asu.edu/research/psyche>

<https://www.facebook.com/Psyche-Mission-1598743977091187/>

Note: New launch date may be in 2022 with different trajectory

Overview

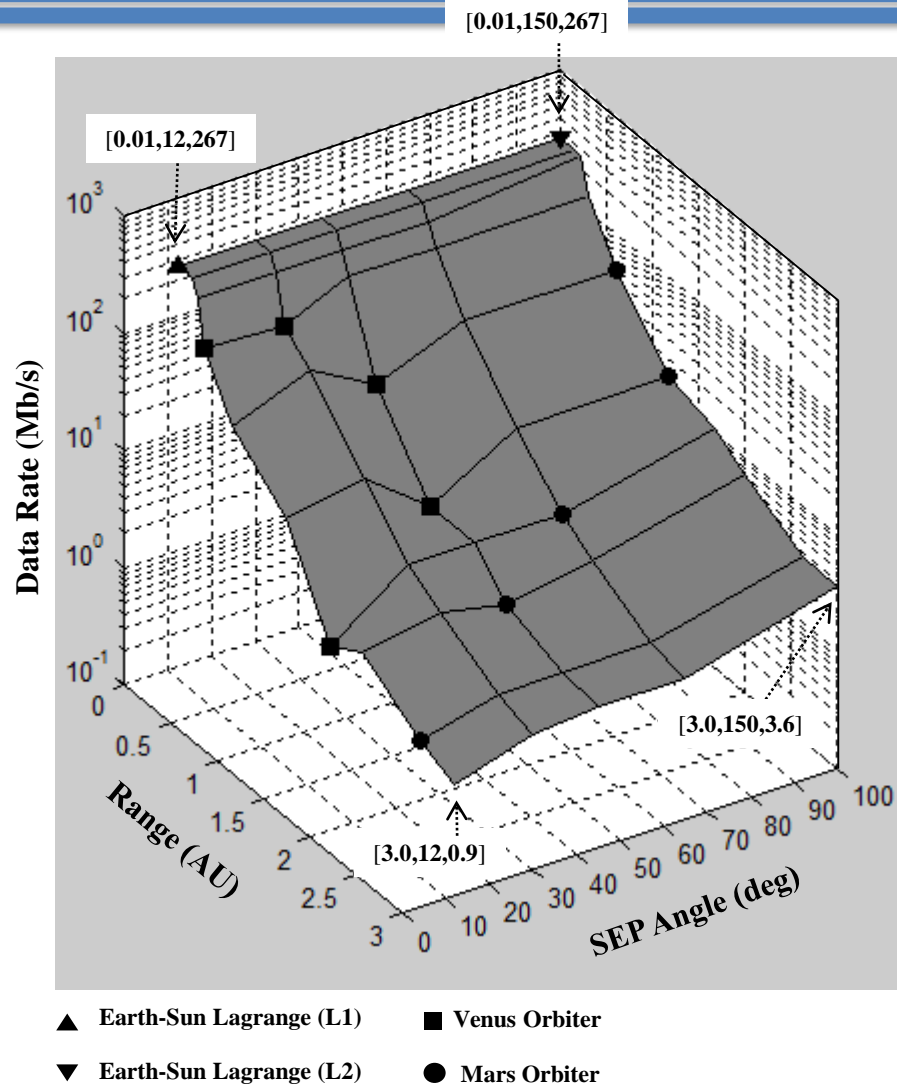
- **Beacon based architecture with existing ground assets for cost-effective demo**
 - Beacon laser beam serves as
 - A pointing reference
 - Low-rate uplink data carrier
 - Requires sensitive detector for dim beacon from deep-space range
 - Downlink is serially concatenated pulse position modulation (SCPPM)
 - Received with a photon-counting detector array retrofitted to 5 m diameter Hale telescope
- **Link demonstration constraints**
 - Ground Laser Receiver restricted to 25°(TBC) SEP angle
 - Expect link outages
- **Psyche Mission to host DSOC**
 - Psyche
 - Ranges from ~ 0.1 - 3 AU
 - Diverse sun angles, air-mass, time of day/year



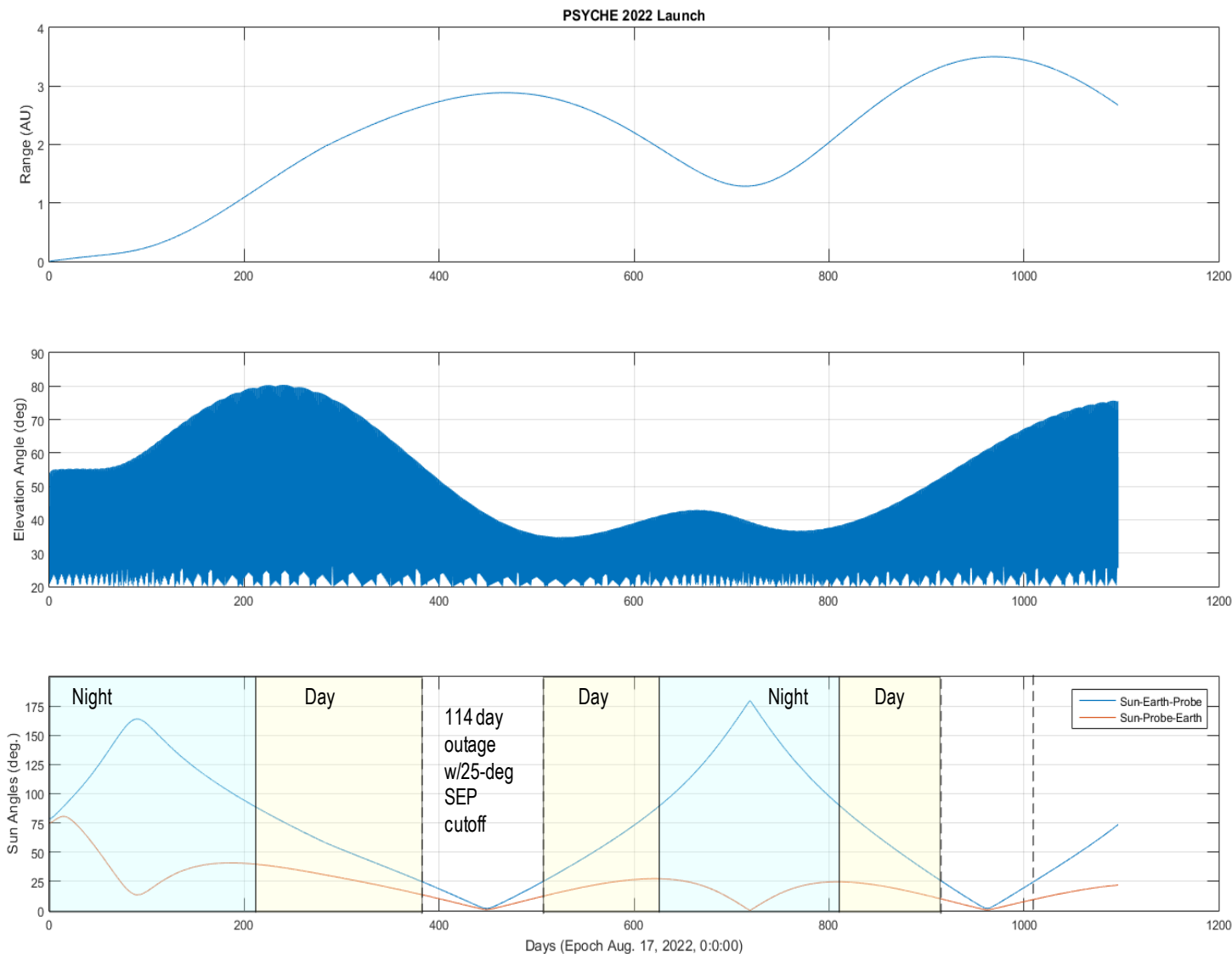
Notional Link Performance

- Range and additive background dependency photon-counting link throughput

- 1550 nm
- 4 W laser average power
- 22-cm aperture diameter
- Serially concatenated pulse position modulation (SCPPM)
- Nominal atmospheric conditions
- 60° zenith angle
- r_0 (day) = 3.6 cm
- r_0 (night) = 5 cm
- Min SEP Angle 12°-25° (TBC)
- 5 m dia. ground collector
- Photon-counting receiver
- At all other ranges 3-4.5 dB margin

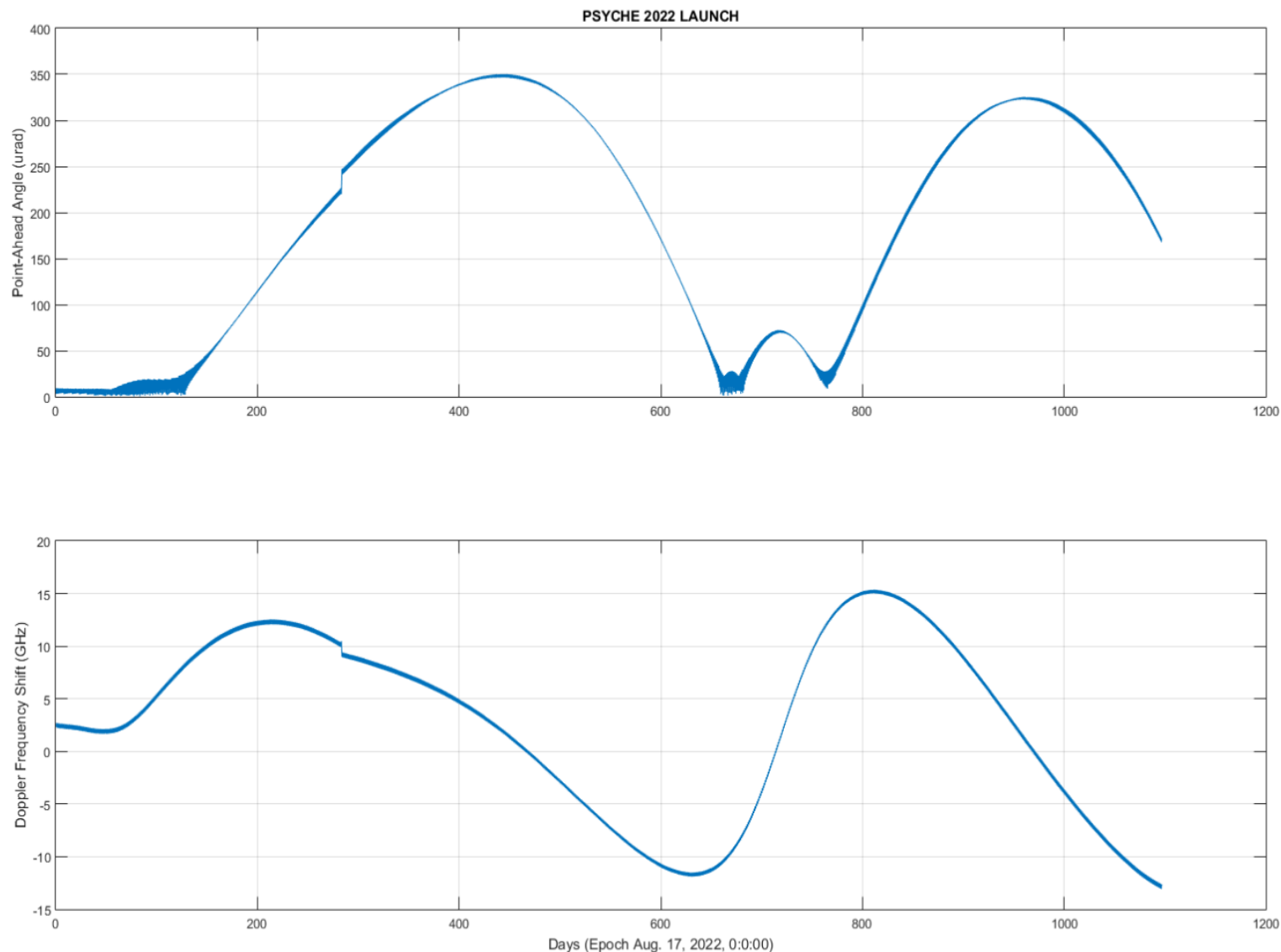


Psyche Link Characteristics: Range, Elevation Angle & Sun Angle



Psyche Link Characteristics:

Point-Ahead Angle & Doppler Frequency Shift



DSOC Space Flight Hardware

Telescope & Optics

Flight Laser Transceiver (FLT) Assembly

- Uplink receiver
- Downlink transmitter

Point-Ahead Mirror

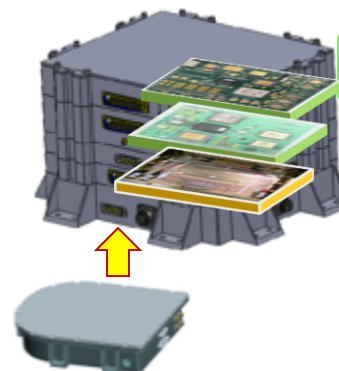


Photon-Counting Camera



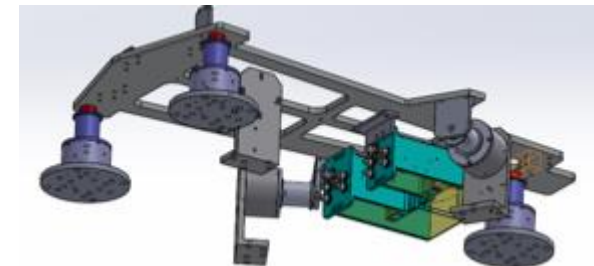
Electronics Box

- Electronics processing & control cards, firmware, software, clock



Laser Transmitter

- High Peak-to-average power

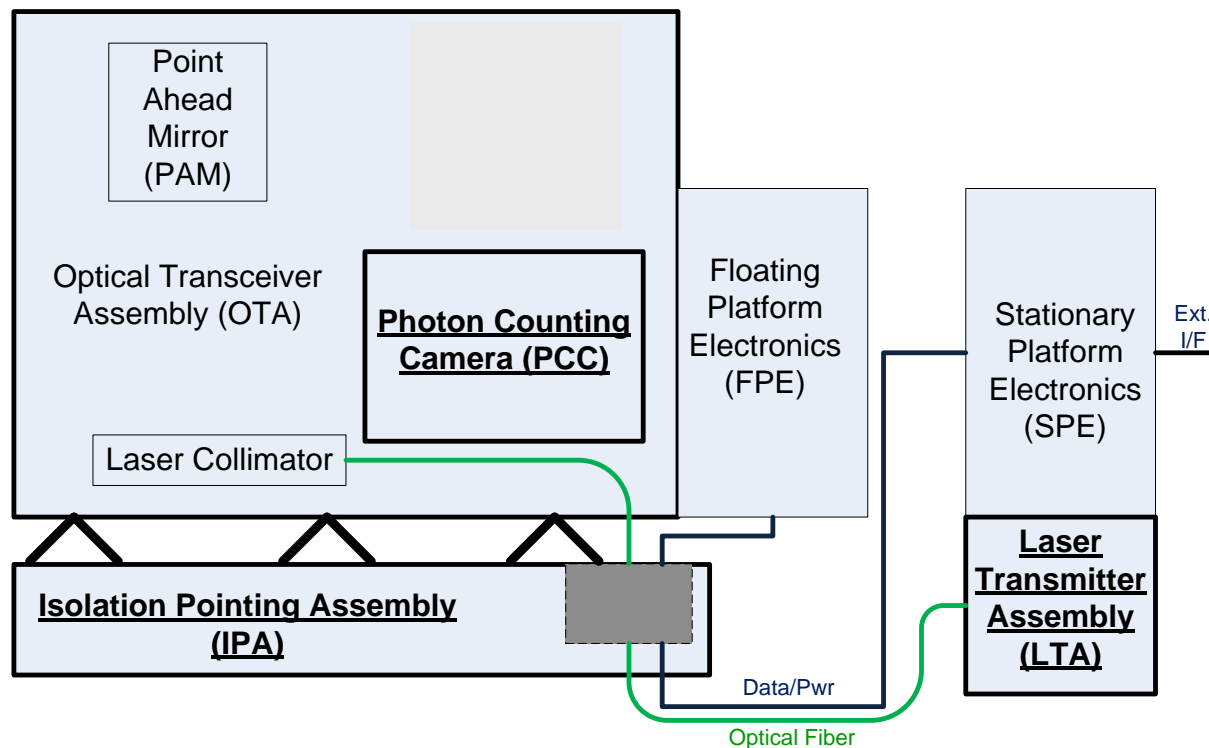


- ### Isolation Pointing Assembly (IPA)
- Steering and line-of-sight (LOS) stabilization

- **Deep-space optical communications Flight Laser Transceiver (FLT) characteristics**
 - *Photon-efficient communications*
 - *Off-axis Gregorian telescope*
 - *Isolation Pointing Assembly*
 - *Photon Counting camera*
 - *High peak-to-average power laser transmitter*
 - *Electronics*
- **Assembly level technologies**
 - *Developed by vendors and at JPL*
- **Integration & testing at JPL**

FLT BLOCK DIAGRAM

- A simplified block diagram of the FLT is shown below:
- Completed development of all “blocks” by EO FY16 under joint STMD/GCDP, HEOMD/SCaN and SMD Discovery funding
 - Tested at unit level
 - Not integrated
 - Initiated testbed for integrated testing



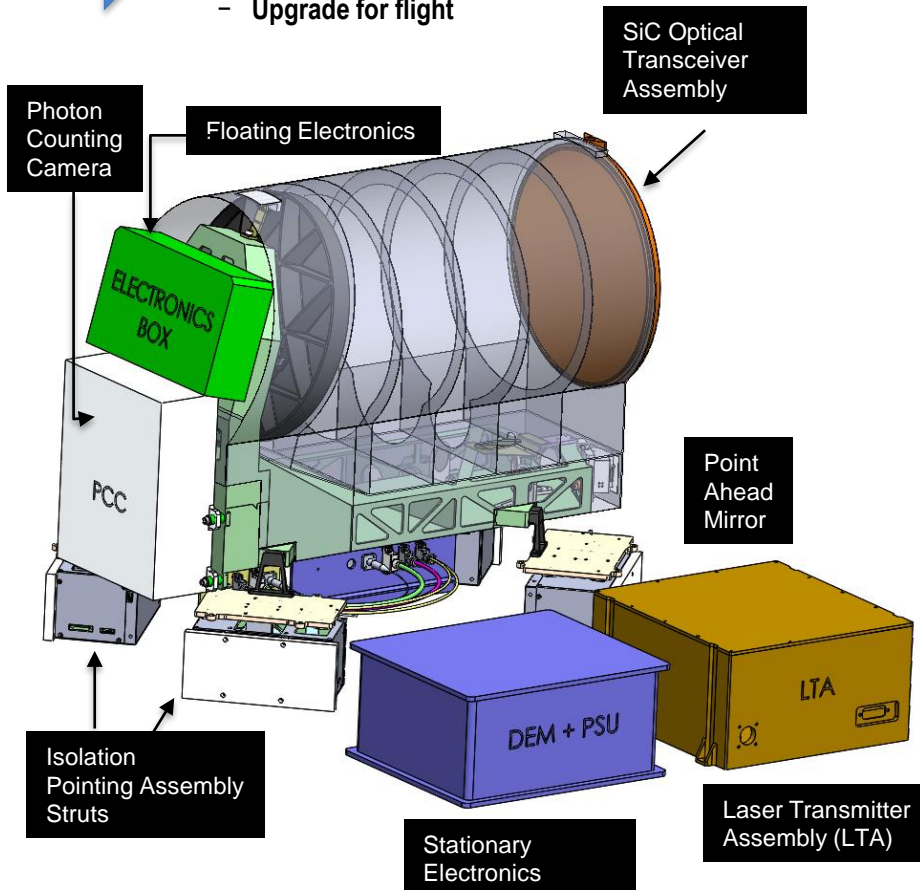
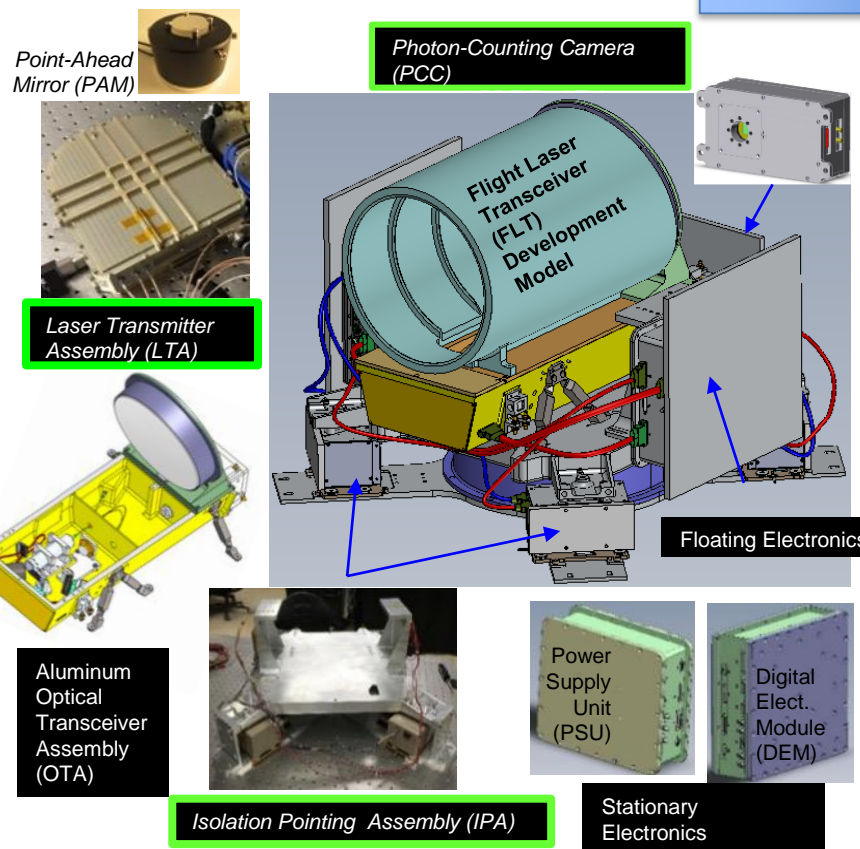
Technology Development versus Flight Model

- Transition technology development model to flight FLT



Transition

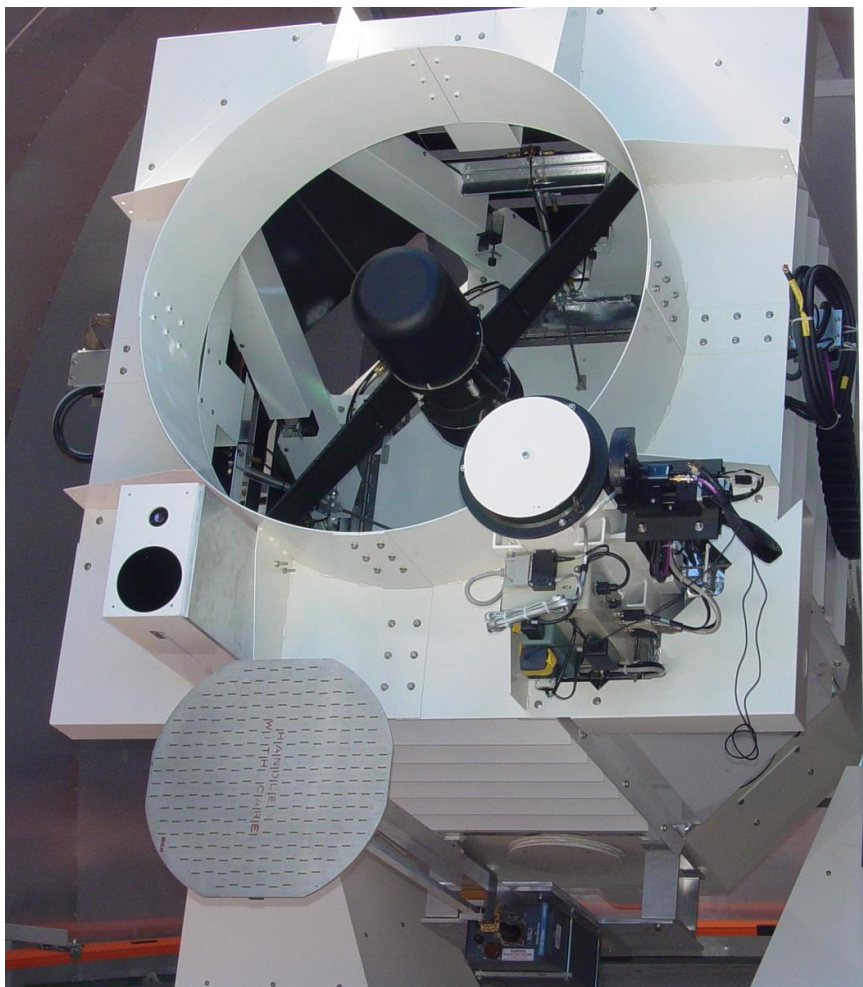
- Achieve mass and power through packaging
- Upgrade for flight



**GCDP Technology
Development Model FLT**

Flight Conceptual Model FLT

Ground Laser Transmitter



Uplink Terminal at Table Mountain

- 1.064 microns
- 5 kW
- Multi-beam
- 1 meter aperture
- Table Mountain (CA) uplink station using OCTL facility (existing and functional)
- Beacon is modulated, but with a limited uplink data rate (Not a Demonstration Requirement)

Ground Laser Receiver



- Located at the Coude or Cassegrain (TBD) focus of the 5 meter Hale Telescope at the Caltech Palomar Observatory
- Current plans are to downlink to Palomar once or twice per month for 2 hours during cruise
- Uses JPL developed 64 element WSi superconducting nanowire single photon-counting detector (SNSPD) array

ARCONS SCIENCE INSTRUMENT



- Photo of a superconducting detector instrument (ARCONS) in a 100 mK cryostat, installed at the Coude focus of Palomar (Courtesy Prof. Ben Mazin, UC Santa Barbara)

Status

- Photon Counting Camera: Characterizing prototype 32x32 InGaAsP detector array w/ microlens array and readout integrated circuit in laboratory; procuring qualified version
- Optical Telescope Assembly: On contract for SiC telescope flight model design and fabrication
- Laser Transmitter Assembly: Verified prototype performance; Limited environmental test and analysis; Working flight implementation strategy
- Isolation Pointing Assembly: Ongoing testing of Prototype; working flight qualification
- Floating Electronics: Architecting with flight qual parts
- Stationary Electronics: Universal Space Transponder heritage architecture; prototype built and in testing; upgrade to flight version

Summary

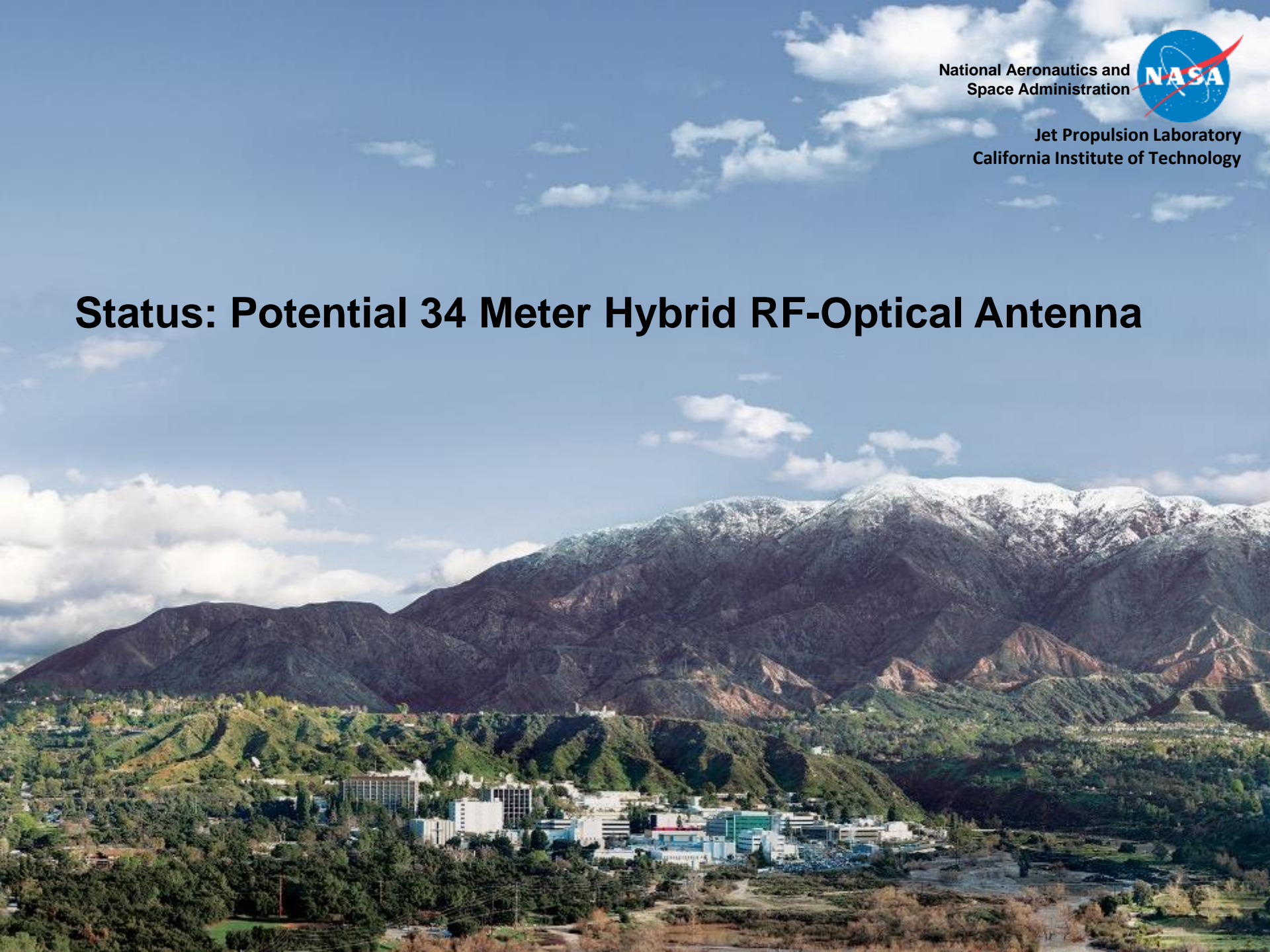
- **Technology Demonstration (TD) opportunity for laser communications**
 - Psyche mission to host TD
 - The DSOC Project is developing a flight and ground sub-system
 - Several new technologies will be tested and verified:
 - Space Photon Counting camera
 - Isolation Pointing Assembly
 - Flight Laser transmitter
 - Ground photon counting detector array
 - Gain deep space optical communications operational experience
 - Planning and scheduling link operations
 - Verifying link acquisition and tracking
 - Evaluating link performance under diverse conditions

National Aeronautics and
Space Administration



Jet Propulsion Laboratory
California Institute of Technology

Status: Potential 34 Meter Hybrid RF-Optical Antenna





Introduction

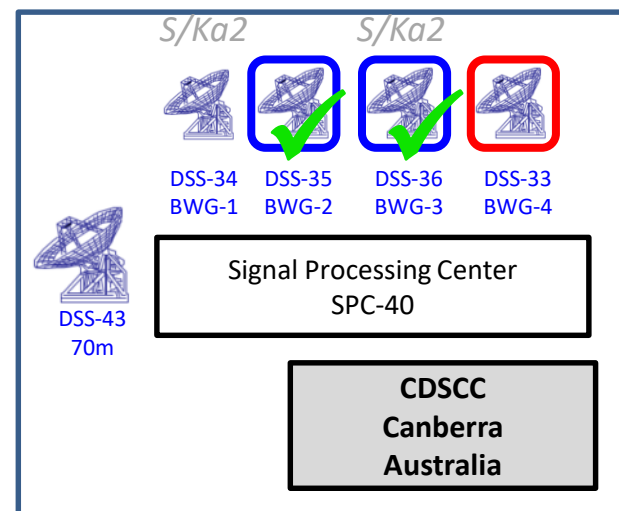
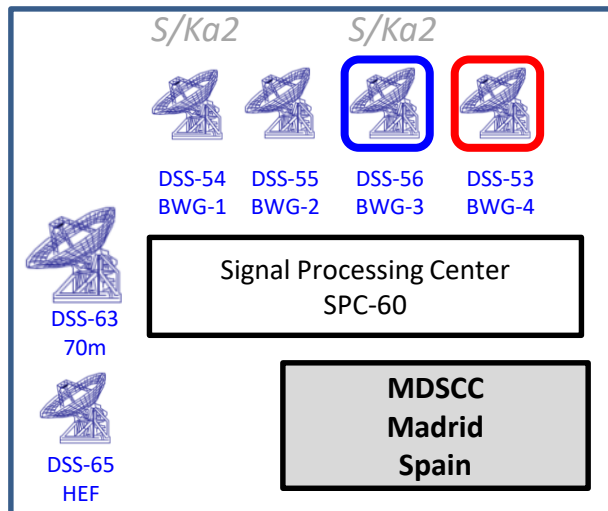
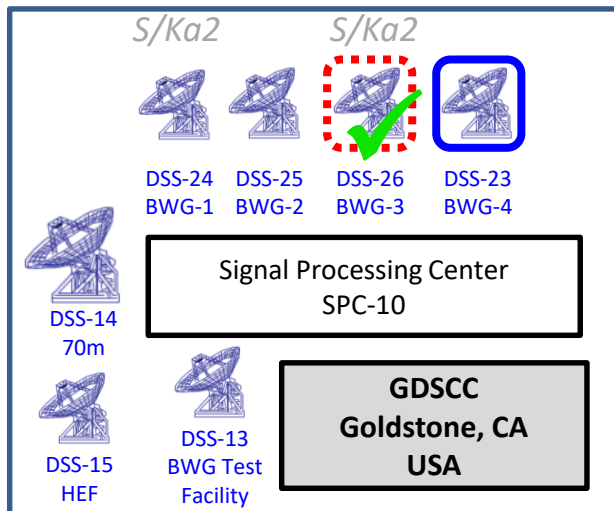


- JPL is proposing to incorporate an approximately 8 meter optical aperture into a 34 meter RF antenna
- Potentially part of the DSN Aperture Enhancement Project (DAEP)
 - No commitment from NASA/SCaN
 - All dates shown are notional but will be coordinated with DAEP
- Still in the initial systems engineering, technology development and validation stage

Thanks to Mark Gatti, Dan Hoppe and Brad Arnold for their contributions to this briefing



DAEP Rollout



DAEP Developments



S S-Band Up/Dn
Ka2 26-GHz Dn
Complete

Station	XX/Ka	S	Ka2
DSS-26		10/2017	(TBD)
DSS-35	10/2014	-	-
DSS-36	10/2016	10/2016	(TBD)
DSS-56	03/2020	03/2020	03/2020
DSS-53	10/2020	-	-
DSS-23	10/2022	-	-
DSS-33	10/2024	-	-



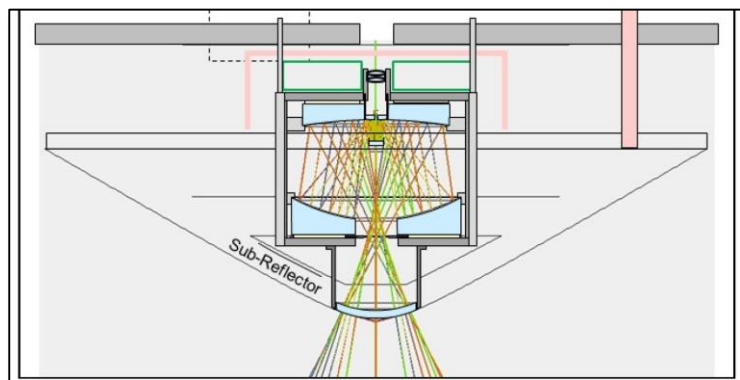
Overview



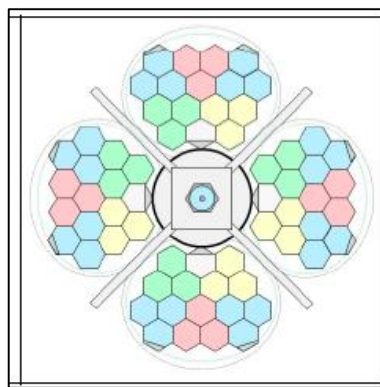
- Transformational development for SCaN for next generation deep space telecom, with feed forward for human exploration support
 - Operational Deep Space Optical capability
 - Ready to augment Discovery optical comm flight demo and early crewed missions
- Leverage earlier NASA-funded studies and tests, include key development gates minimize risk to NASA
- Implementation approach is to integrate new 8-m optical apertures with ongoing new 34m BWG antennas
- Minimize impact to baseline DAEP RF antenna schedule
 - Potentially, both hemispheres covered with optical deployments at GDSCC and CDSCC

- Optical Design

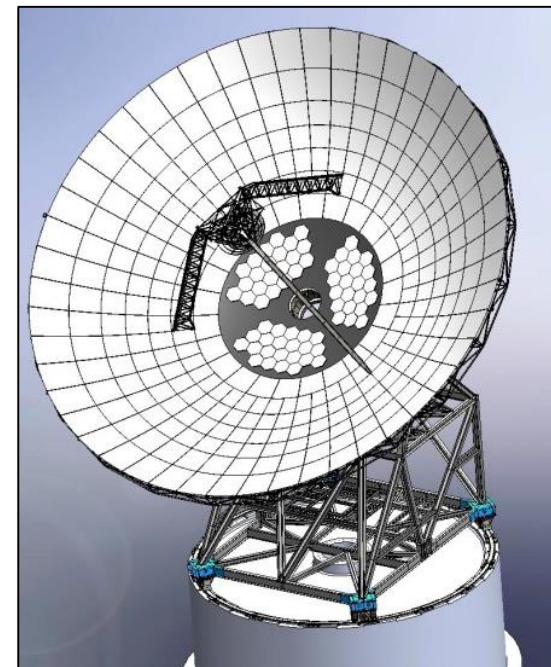
- Adapt two planned 34 m BWG for DAEP
 - Small loss to RF performance – studies ongoing
- Primary spherical mirrors replace inner RF panels
 - Small loss to RF performance – studies ongoing
- Spherical aberration correction optics and receiver package located behind RF subreflector
- Initial risk reduction development at GDSCC's DSS-13
 - Tripod vs. quadripod at production BWG



Spherical Aberration Correction Optics
behind Subreflector



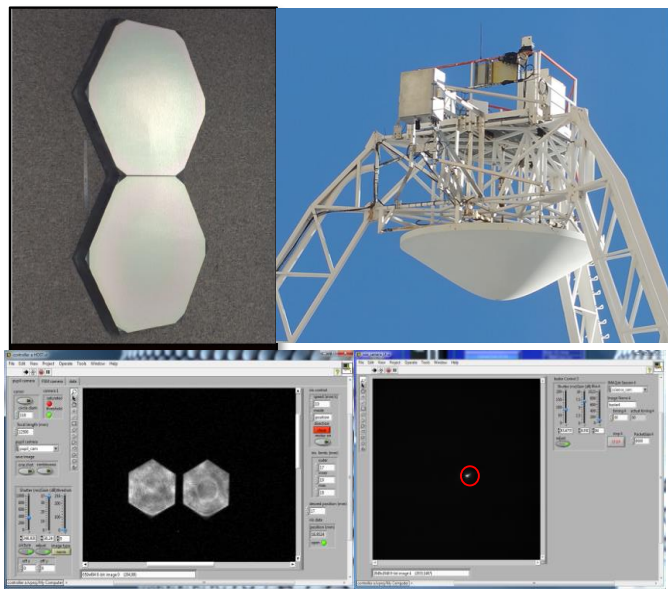
DAEP 34m Design



DSS-13 8 m Primary
Surface Plan

Developments To Date

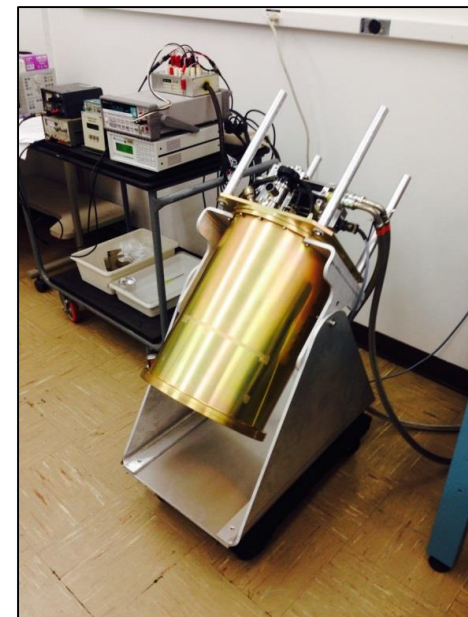
- Early optical studies with pair of 35 cm panels DSS-13 complete, fielded second generation focal plane assembly last FY
- Low temperature cryo demonstrated (0.5 K at detector)
- Completed tipping and mechanical vibration tests, vetting design



DSS-13 2-Mirror Test

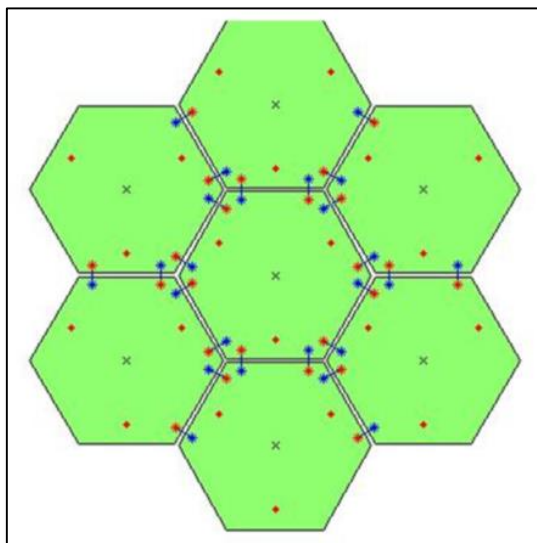


Cryo Package Prototype



Cryo Tipping Test

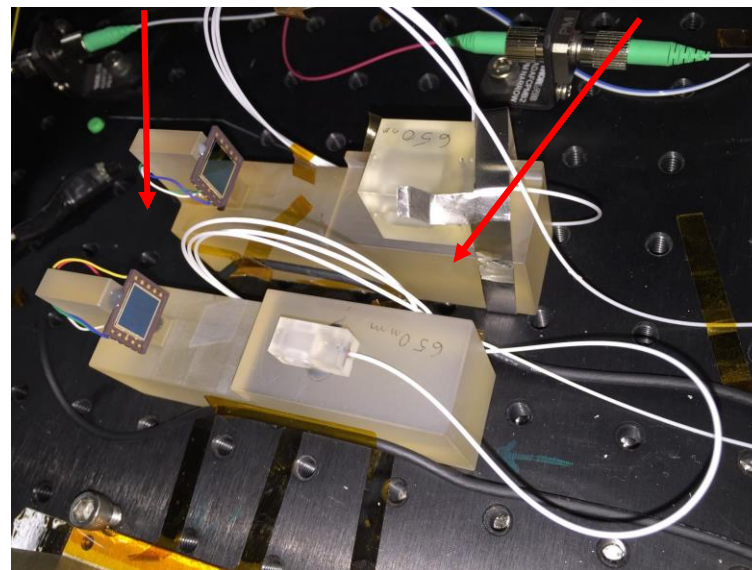
- Edge sensors and control will be required to maintain overall surface alignments.
- Early development and testing of sensor system including outdoor testing is ongoing.



Edge Sensor Layout in Lattice

Quad Cell Side

Transmit Side



Early Testing of 2 Versions of the Detector System



Proposed Development Plan



- Preliminary development & analysis FY'17 – FY'19
 - Optical system analysis
 - Stray light analysis (complete by end of April)
 - Link budgets
 - Supportable solar angles
 - CDSCC atmospheric study
 - Equipment installation plus 2-3 years data collection
 - O&M considerations
 - Refine costing estimates



Proposed Development Plan (cont'd)



- Main technology demonstration and development gates
 - By Jan-2020
 - Seven 0.5m-element Non-Recurring Engineering study at DSS-13
 - Equivalent ~1.2 m demonstrated
 - Risk retired: Proof of concept demonstration showing alignment functionality of array with lower cost smaller optical elements
 - By Sep-2021
 - Sixteen 1.1 m production element “pod” + aberration correction optics at DSS-13
 - Equivalent ~4.15 m demonstrated
 - Risks retired: Performance of sub-array with full sized elements and optics demonstrated
 - Challenge: space based signals to test against (LCRD, stars, LEOs w/LRA, etc.)
 - Technical options will be considered
 - Psyche launches late 2022 or 2023 - augmentation to end of DSOC demonstration feasible



Proposed Development Plan (cont'd)



- Final build out and test
 - By Oct-2023
 - 64 elements (1.1 m) installed at DSS-13
 - Optical detector and receiver build, test and installation
 - Full equivalent 8 m demonstrated
 - By Oct-2024
 - Move equipment to DSS-23
 - Full integration and test complete
 - DSS-23 RF capability transferred to operations.
 - Optical capability will initially be run as a demonstration, until experience is gained in operating and maintaining the capability



Development Plan (cont'd)



- DSS-33
 - Start antenna build in FY'21
 - Complete full I&T and delivery to DSN by Oct-2026
- Additional requirements to modify BWG antenna
 - Preliminary analysis shows low risk forward, detailed analysis to go
 - Inner rings of RF panels not populated
 - RF subreflector reshaped, RF panels re-positioned
 - Antenna subreflector modified to accept Spherical Aberration Corrector, receiver and cryo equipment behind subreflector



10 m RF-Optical Hybrid



- 10-m equivalent diameter optical
 - Under study now
 - Early assessment suggests some redesign of 34m BWG would likely be required (f/D optics)



Conclusion



- The RF/Optical DSN antenna will be a transformational development
- Clear path to implementation with feed forward for next generation deep space telecom, including human exploration
- Plan minimizes impact to RF antenna development
- Delivers DSS-23/33 8 m optical hybrid antennas in 2024 and 2026
- Initial development and plan have been prepared
- Minimizes risk to NASA resources by scheduling two key development gates